OBSERVATIONS ON OSMOREGULATION IN THE ARCTIC CHAR (SALVELINUS ALPINUS L.)[1]

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The different groups of euryhaline fishes have developed somewhat different mechanisms for maintaining the relative constancy of the concentration of their "milieu interieur" in the face of large changes in the external osmotic pressure. Following such an external change, many change their internal concentrations only transitorily, in the same direction as the external variation. A return to essentially the original conditions usually follows shortly (in adult female eels (*Anguilla*): Boucher-Firly, 1935; Duval, 1925; in sticklebacks (*Gasterosteus*); Gueylard, 1924; Koch and Heuts, 1943; in killifish (*Fundulus*): Burden, 1956). Anadromous salmonid fishes, however, have long been known to regulate their blood concentrations on two distinct levels (probably the end-points of an acclimation curve). In almost all such salmonids studied so far, the transition from salt to fresh water (or the reverse) is accompanied by a fall (or rise) in total blood concentration of about 25% (the Atlantic salmon, *Salmo salar,* and the Chinook salmon, *Oncorhynchus tshawytscha,* however, change by only 12% (Fontaine and Koch, 1950; Greene, 1926)). Plasma freezing point depressions vary from species to species, being 0.67–0.90° C. in salt water, 0.55–0.72° C. in fresh water (Benditt *et al.*, 1941; Fontaine, 1943, 1948; Fontaine, Callamand and Vibert, 1950; Fontaine and Koch, 1950; Greene, 1904; Kubo, 1953).

The Arctic char (*Salvelinus alpinus* L.) is an anadromous salmonid fish common in fresh and coastal salt waters throughout most of the Arctic. As in other sea-going char, its migrations from fresh to salt water and back again are somewhat different from those of other salmonids in that its winter periods in fresh water lakes and rivers are long compared to its summer periods in the ocean, rather than vice versa (Andrews and Lear, in press; Backus, 1952; Sprules, 1953). Osmoregulation in this form has not been studied, probably due to its inaccessibility. The present paper describes some observations made on the osmoregulatory abilities of adult Arctic char on their return (spawning) migration to fresh water after a summer in the ocean.

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The material is of a preliminary nature in many ways, but serves to show that the Arctic char is similar to other salmonid fishes in regulating its blood concentration on two levels. Agreement between experimental results and data obtained from fish living in fresh and salt waters provides a basis for further experimental study of osmotic phenomena during the migrations of these fish. Some data on regulation of muscle concentrations are also presented. Differences in results obtained from char in northern Labrador and Hudson Bay indicate the possibility of physiologically different populations in this species.

Materials and Methods

Regulation of total plasma concentration, chloride and potassium, and of total muscle solids, chloride, and potassium was studied in mature adult char of both sexes by means of observations on fish living in salt or fresh water, and by time series of observations immediately following direct transfers of fish from salt to fresh water. Conditions of temperature, stage in life cycle, etc., were kept fairly constant in these experiments. Char were taken by means of gill nets from Hebron Fjord, Labrador, and Hudson Bay near Churchill, Manitoba, during late July and early August of 1954 and 1955, respectively.

Seven char were used to establish the normal salt water ranges for plasma freezing point and chloride concentration in fish in Hebron Fjord (water of 28.6 ‰ salinity, 9° C. temperature). Five Churchill char were used similarly, observations on these consisting of plasma chloride and potassium concentrations, and total muscle solids, chloride, and potassium concentrations (Hudson Bay water was of approximately 26 ‰ salinity, 10–12° C. temperature).

Fresh water ranges for plasma freezing point and chloride concentration were determined at Hebron in several small land-locked char from a small lake, in some pre-sea-run parr from a river, and in an adult char that had returned to fresh water by itself. No fresh water char were obtainable at Churchill.

The osmotic stresses these fish undergo during the course of their migrations from the sea were approximated by transferring four Hebron fish and seven Churchill fish directly from salt to fresh water. Temperatures at Hebron were: salt water, 9°, fresh water, 5–10°; at Churchill: salt water, 10–12°, fresh water 14–16°. Changes in plasma freezing point with time were followed in three of the Hebron fish via serial blood samples taken at intervals up to 77 hours following transfer. The fourth fish was sampled initially and after 77½ hours. Two of the Hebron char were then returned to the Fjord and sampled again following death (after some fifteen hours in salt water).

Only two of the Churchill char survived for more than one hour after transfer from salt to fresh water—these for two and six hours, respectively. Blood and muscle concentrations were determined in these, after the periods mentioned, as in the salt water fish. The approximately 5° C. thermal shock to which these fish were subjected, combined with a lack of running fresh water, hence a need for aeration by hand dipping, probably explains in great part the lowered survival as compared with the Hebron fish. The speed with which death followed transfer makes it seem unlikely that this is the complete explanation, however.

Blood samples were taken via heart puncture from all fish. The samples were heparinized, centrifuged, and the plasma pipetted off. Plasma freezing points

were determined at Hebron using the method of Pounder and Masson (1934) modified for field use (Scholander *et al.*, in press). Plasma chloride determinations were made using the method of Schnohr (1934). Plasma potassium concentration was determined on the Churchill samples following dilution with Pyrex-distilled water on a Baird Associates internal standard flame photometer. Probably due to coagulation of the proteins in these samples, which may have interfered with activation of the ions by the flame, only three of these analyses gave what appear to be reasonable values.

Four samples of tissue from the dorsal muscle mass, averaging about 100 mg. wet weight, were also taken from each of the Churchill fish. Total solids were determined by weighing these before and after complete drying in an oven at 105° C.

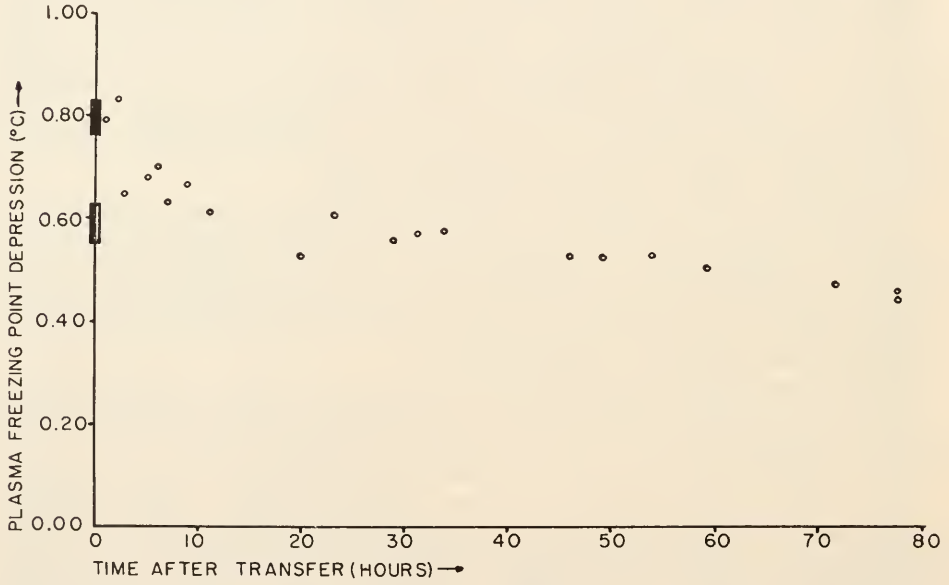

FIGURE 1. Changes of plasma freezing point depression with time following direct transfer from salt to fresh water of Arctic char (*Salvelinus alpinus* L.) from Hebron Fjord, Labrador. Ranges for fish naturally acclimated to salt water (black bar) and fresh water (black and white bar) indicated on ordinate. Temperature 5–10° C.

Following digestion with concentrated nitric acid and 30% hydrogen peroxide, duplicate chloride and potassium analyses were carried out. Methods were as above.

Precision of the freezing point determinations is ± 0.05° C. Plasma chloride analyses agreed within 1%, as did total muscle solids. Muscle chloride and potassium duplicates agreed within 5%.

Results and Discussion

Figure 1 shows the behavior of total blood concentration in control and experimental char from Hebron Fjord. The total plasma concentration in Hebron char living in fresh water is about 25% lower than the salt water concentration. The char is thus like most other anadromous salmonids in this regard. Beginning

two hours after transfer from salt to fresh water, the experimental fish also decreased their plasma concentrations by about 25% over a period of approximately twenty hours. They then became fairly stable. It therefore seems that sudden transfer experiments duplicate at least some of the physiological events occurring during the migrations of these fish. This last might have been expected, since individual salmonids frequently make the transition from salt to fresh water and back again as rapidly as they can swim through the estuaries involved (Benditt *et al* 1941; Greene, 1910; Killick, 1955).

The continuing decrease in plasma concentration below the normal fresh water level which occurred in the experimental fish after about 35 hours in fresh water could have been the result of several influences. First, the fish were not fed; second, they may well have lost salt via their urine as a result of having been handled

TABLE I

Blood concentrations in arctic char

Source of fish	Plasma Δ_F (° C.)	Plasma $[Cl^-]$ (meq./l.)	Equivalent Cl^- Δ_F (° C.)*	Plasma $[K^+]$ (meq./l.)
Hebron Fjord, salt water	0.80	148	0.28	
	0.80	191	0.36	
	0.81	191	0.36	
	0.82	213	0.40	
	0.82	214	0.40	
	0.83			
	0.76			
Hebron Fjord, fresh water (land-locked)	0.59	144	0.27	
	0.61	144	0.27	
	0.63	161	0.30	
Churchill, salt water		177	0.33	5
		153	0.28	8
		156	0.29	1
		130	0.24	1
		132	0.25	2
Churchill				
2-hr. transfer		134	0.25	1
6-hr. transfer		124	0.23	8

* Equivalent $Cl^-\Delta_F$ calculated from: $\Delta_F = 1.86\ [Cl^-]$

(laboratory diuresis of Grafflin, 1931, 1935, and Forster, 1953); and third, their skin permeability, hence rate of water uptake in a hypotonic medium, may well have been increased as a result of loss of slime during handling.

The two Hebron char transferred back to the Fjord after the experiment, after fifteen hours in salt water, had plasma freezing points of $-0.75°$ C. This is essentially the original salt water value.

Table I summarizes the data on blood concentrations obtained from both Hebron and Churchill control fish and Churchill transfers. With the exception of the first salt water char from Hebron, the calculated equivalent Cl freezing point is essentially a constant fraction of the total freezing point (45–50%). More exact regulation of the concentrations of other plasma components is thus indicated. Similar behavior of chloride and total concentrations has been noted in brook and brown trout (unpublished data of the writer and van Dam). Fontaine, Callamand and

Vibert (1950), however, found a decrease of only 4% in plasma chloride in Atlantic salmon (*Salmo salar*) when total concentration dropped 13%.

The Churchill material generally supports the Hebron results. Plasma chloride concentration in the Churchill fish in fresh water for six hours is approximately 18% lower than the mean plasma chloride concentration for Churchill char in salt water. Plasma freezing point behaves similarly in the Hebron char. Note, however, that plasma chloride concentrations in the Churchill fish are generally much lower than in the Hebron fish. The mean difference of 20% seems too large to be the result of acclimation to differing salinities (the salinities differing only by 10%.). The marked differences between Hebron and Churchill char with respect to survival following transfer were noted earlier. Even allowing for the poor conditions encountered at Churchill it seems likely that real physiological differences exist between these populations. Marked differences in growth characteristics differentiating these two groups (Andrews and Lear, in press; Backus, 1952; Sprules, 1953; unpublished data of the author) also make this seem likely (though differences in food supply might well account for this last).

TABLE II

Muscle concentrations in Churchill arctic char

Source of fish	Total muscle solids (gm./kg. wet weight)	Muscle [Cl^-] (meq./kg. wet weight)	Muscle [K^+] (meq./kg. wet weight)
Salt water	276	22	123
	224	20	130
	266	8	120
	226	8	120
	260	6	125
2-hr. transfer	242	4	127
6-hr. transfer	244	3	150

Table II indicates that the one Churchill fish surviving transfer for six hours regulated total muscle concentration very well. Muscle potassium, however, seemingly increased markedly. The concentrations of the same muscle components in brook and brown trout under similar conditions behave very differently, however (data of the author and van Dam). In these other forms there is a close parallelism between changes in muscle concentrations and changes in the blood. Further work on the char is obviously needed.

In closing it should be noted that the blood and muscle potassium concentrations reported by Jones (1956) for fresh water brown trout agree very well with the figures given in Tables I and II for the Churchill salt water char (low plasma potassiums excepted).

SUMMARY

1. Adult Arctic char (*Salvelinus alpinus*), taken in summer from Hebron Fjord, Labrador, and Hudson Bay near Churchill, Manitoba, were transferred directly from salt to fresh water under fairly constant conditions.

2. Decreases in blood freezing point and chloride concentration of the order of 25% were found, the char thus being like most other anadromous salmonids in this

respect. The possibility of much better regulation of muscle concentrations is indicated.

3. Data are presented on plasma freezing point, chloride, and potassium, muscle solids, chloride, and potassium.

4. Physiological differences between populations of char are indicated.

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